Study of the directivity of a half-loop antenna coupled with magnetic metamaterial cells

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***Abstract*—The effect of associating Split Ring Resonators (SRR) or C resonators cells with a half-loop antenna is studied. Adding SRRs will shift down considerably the resonance frequency but the directivity will be almost the same. SRRs are good candidate for antenna miniaturization. Adding C resonators will increase more the directivity while the frequency shifting is not as important as with SRR cells. With a ground plane of 10cm x 10cm, two cells of C resonators coupled with a half-loop antenna can have a directivity of 7.35dB at 920.4MHz. The ground plane can be increased to get better performances.**

Keywords— loop antenna; metamaterials; directivity

I. INTRODUCTION

The half-loop antenna was coupled with one or an array of magnetic metamaterial cells to shift down by 70% the resonance frequency then, miniaturize the structure. The addition of magnetic metamaterial cells in the near-field of the half-loop changes the radiation pattern by focusing the energy in one direction instead of having a null in this direction [1], [4]. Small antennas are known to have low efficiency. But, the performances of the half-loop metamaterial-inspired antenna depend on the type of the magnetic metamaterial cells coupled with them.

A superdirective array of resonant dipoles was designed in [5] by associating an active element with passive elements. In our previous works [3], [4], our target were to conceive a small antenna with high efficiency (71% measured efficiency). SRR gave the best results among the magnetic metamaterials studied. In this work, a new magnetic C resonators cell is associated with a half-loop antenna to increase the directivity. Firstly, two cells of SRRs are added above a half-loop and then a cell of two C resonators. Those results will be compared. All results presented in this paper are got by simulation with HFSS.

II. HALF-LOOP ANTENNA WITH SRR CELLS

A. One SRR cell associated with a half-loop

The basic structure consists of a rectangular half-loop antenna of 44.4mm total length, initially resonating at 3.9GHz, printed on a duroïd substrate (ε_r = 2.2, h = 0.78mm and $tan\delta$ = 0.0009). Then associated with one SRR cell of external dimension 25mm x 25mm. The distance between the SRR cell and the half-loop is 0.1mm. The resulting antenna is working at a measured frequency of 876.5MHz. The simulated frequency is 881MHz. The antenna structure with the dimensions of the SRR cell are depicted in Fig. 1. The simulated directivity is 4.2dB (Fig. 2).

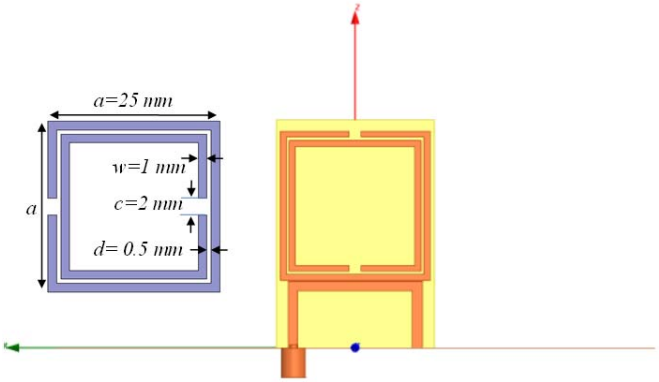

Fig. 1. Structure of the half-loop antenna with one SRR cell.

The simulated gain is 3.8dBi and the measured one is 2.8dBi with a 10cm x 10cm ground plane [4]. Therefore the efficiency is 91%. One can notice that the radiation pattern is focused in z axis where it is null in the case of the half-loop without SRR cell [3], [4].

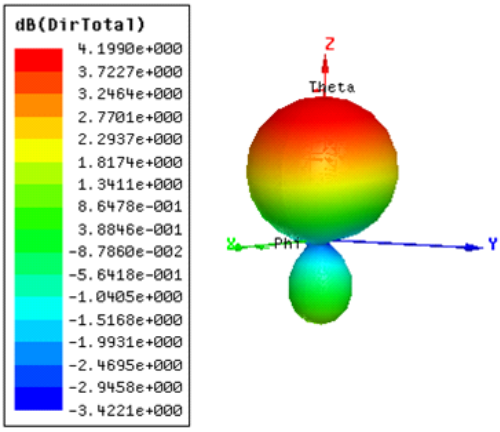

Fig. 2. Simulated directivity of the half-loop associated with one SRR cell.

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In order to ameliorate the antenna performances, another cell of SRR is added to this structure.

B. Two SRR cells associated with a half-loop

Instinctively, one can add a second SRR cell above the half-loop to enhance the gain or the directivity of the antenna. Fig. 3 illustrates this structure. The second SRR has the same dimensions as the previous one.

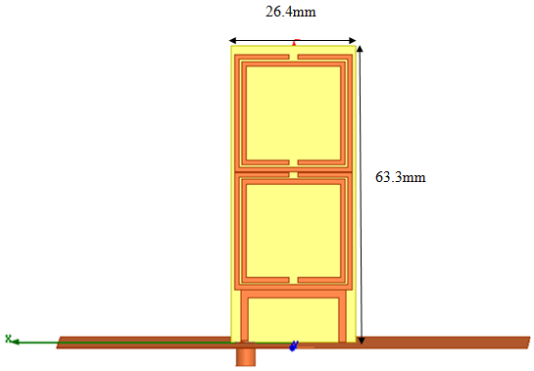

Fig. 3. Structure of the half-loop antenna in presence of two SRR cells.

The new simulated resonance frequency is 739MHz (Fig. 4) i.e. a frequency shifting of about 81% compared to the working frequency of the half-loop antenna alone (3.9GHz). The dimension of the duroïd substrate is 26.4mm x 63.3mm. Therefore the size of the radiating element is $\lambda_0/7$ x $\lambda_0/15$. The antenna is electrically small with a realized gain of 3.13dBi (Fig.5).

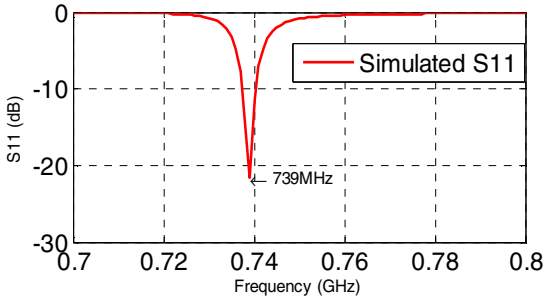

Fig. 4. Return loss of the half-loop in presence of two SRR cells.

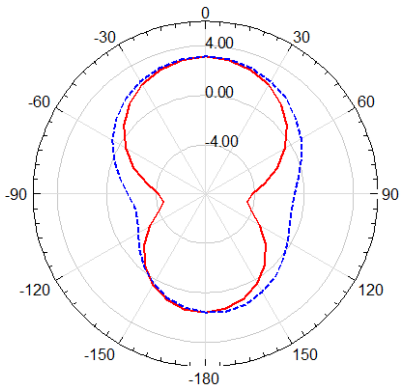

Fig. 5. Simulated gain of the half-loop antenna in presence of two SRR cells, E-plane (continued), H-plane (dashed).

The directivity of the antenna (3.53dB) is presented in Fig. 6. The efficiency is the same as in the case of half-loop in presence of one SRR cell i.e. 91%.

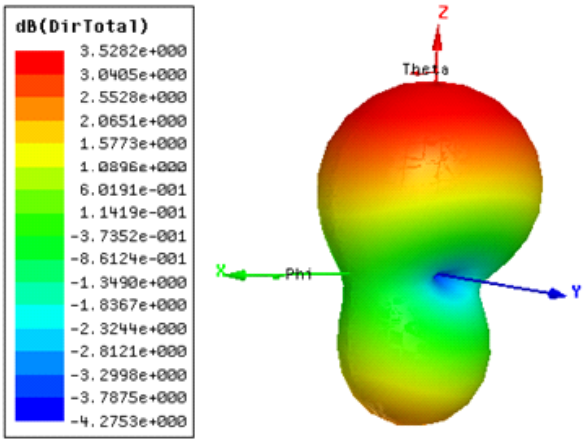

Fig. 6. Directivity of the half-loop antenna in presence of two SRR cells.

The frequency shifting is about 142MHz (16%) while both simulated gain and directivity decreased. Even in a lower frequency, the half-loop antenna with two SRR cells has less gain than the half-loop with one SRR cell but the efficiency remains the same. It can be explained by the loss generated by the second SRR. The 3dB aperture is the same for both structures. But, as the resonance frequency decreases and the new structure is larger, the back radiation increases. To avoid this, C resonators which have less metallic strip than the SRR, are coupled with the initial half-loop antenna.

III. HALF-LOOP ANTENNA WITH C RESONATORS

A. One C resonators cell case

One C resonators metamaterial cell is composed of two C resonators oriented inversely relative to each other. The external dimensions of a C resonators cell are the same as those of the SRR used above (25mm x 25mm). The strip width and the gap are 1mm and 1.8mm respectively. The distance between the two C resonators is 0.3mm. Fig. 7 depicts one C resonators cell coupled with the same half-loop antenna of Fig.1.

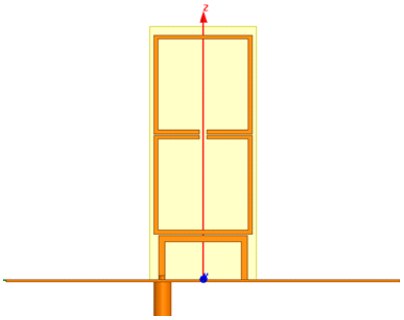

Fig. 7. Structure of the half-loop antenna in presence of one C resonators cell.

The resonance frequency is 945MHz but the structure is not well matched as the return loss is about -5dB. Instead of that, the realized gain is 2.73dBi (Fig. 8) and the directivity is 4.95dB (Fig. 9). Consequently the efficiency is 60%.

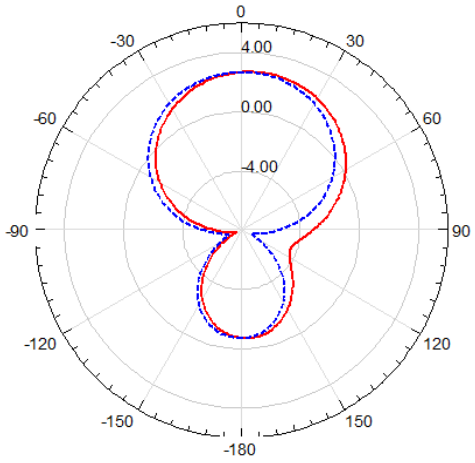

Fig. 8. Simulated gain of the half-loop antenna in presence of one C resonators cell, E-plane (continued), H-plane (dashed).

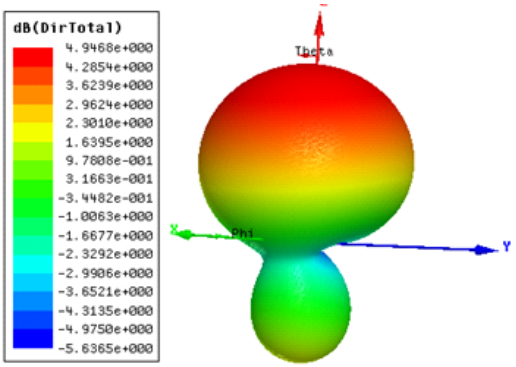

Fig. 9. Directivity of the half-loop antenna in presence of one C resonators cell.

With about the same size of the whole antenna, the structures with 2 SRR cells and with one C resonators cell are comparable. The realized gain and the directivity are almost the same. The only difference is the resonance frequency. Then, SRR cells can be used to work at a lower frequency but C resonators cells permit to have a higher resonance frequency. The effect of adding two C resonators cells to the half-loop is discussed later.

B. Two C resonators cells case

Two C resonators cells are associated with the half-loop antenna. The structure can be seen in Fig. 10. The distance between two cells is 0.3mm. Then the periodicity is 50.6mm. The ground plane is always 10cm x 10cm. The new resonance frequency is 920.4MHz (Fig. 11). In fact, the frequency shifts down by 2.6% by adding another cell of C resonators, as the total length increases. One can notice that the structure is better matched.

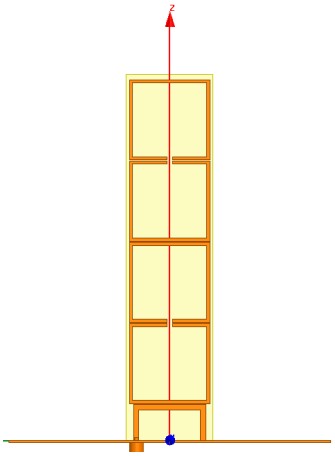

Fig. 10. Structure of the half-loop antenna in presence of two C resonators cells.

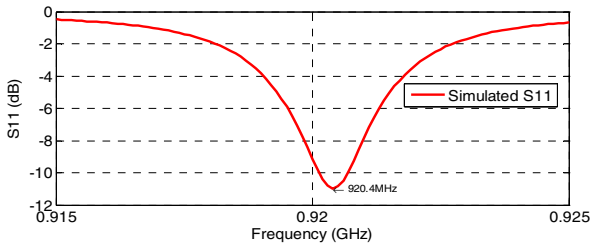

Fig. 11. Return loss of the half-loop antenna in presence of two C resonators cells.

The realized gain is 2.27dBi (Fig. 12). The back radiation which is greater than that of the half-loop in presence of two SRR cells, is due to small size of the ground plane. The directivity increases by 2.4dB compared to that of the structure with one C resonators cell. Fig. 13 presents a directivity of 7.35dB. The efficiency is 31%. This difference between the directivity and the gain could be explained by the loss included in the structure with two C resonators cells which has more radiating surface than the structure with two SRR cells. The 3dB angle decreases to 70° instead of 130° in the case of the use of one C resonators cell.

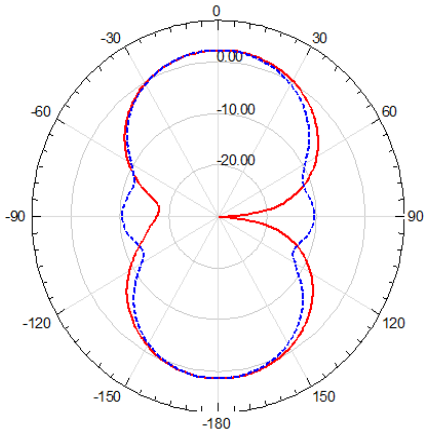

Fig. 12. Simulated gain of the half-loop antenna in presence of two C resonators cells, E-plane (continued), H-plane (dashed).

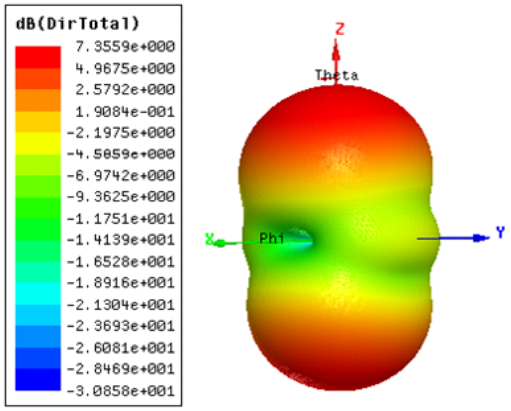

Fig. 13. Directivity of the half-loop antenna in presence of two C resonators cells.

The half-loop antenna associated with two C resonators cells is more directive but less efficient than the half-loop associated with two SRR cells. The next step of our study is to minimize the loss of the antenna in order to increase its efficiency. Then use this antenna for applications that need more directivity.

IV. CONCLUSION

Two types of magnetic metamaterial cells have been considered with their effects on the directivity of a half-loop antenna. With the same size of the ground plane and the same dimensions of the radiating element, in one hand, adding SRR cell tends to decrease more the frequency (miniaturization) than adding C resonators cell. But in the other hand, C resonators can be used to increase the directivity of the structure. In fact, the antenna performances can be improved by increasing the ground plane.

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[5] O. S. Kim, S. Pivnenko,and O. Breinbjerg, "Superdirective magnetic dipole array as a fist-order probe for spherical near-field antenna measurements," IEEE Transactions on antennas and propagation, vol.60, no. 10, October 2012.

- The slide 2 shows the effects of adding one SRR cell above a half-loop antenna. The resonance frequency of the resulting antenna is 77% less than the resonance frequency of the half-loop antenna alone. The radiation pattern becomes focused in z-axis instead of being null in this direction.
- The slide 3 compares the results got by coupling one and two cells of SRR or C resonators with a half-loop antenna. SRR permits to shift down mainly the resonance frequency but C resonators are increasing more the directivity. The H-field distribution is also presented in the case of two SRR and two C cells. .
- The slide 4 summarizes and compares the engendered effects of the SRR and C shaped resonators on the half-loop antenna parameters.

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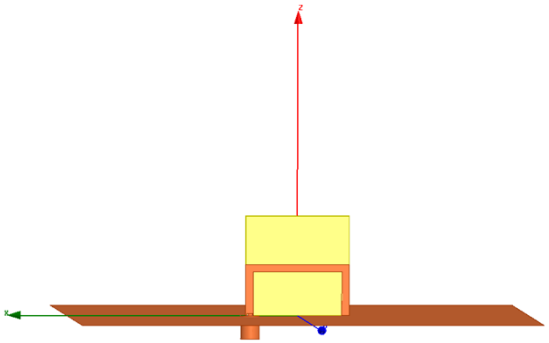
Half-loop antenna coupled with magnetic metamaterial cells



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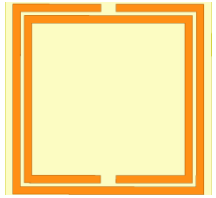
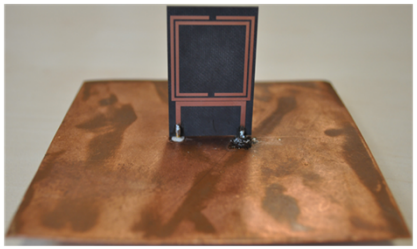
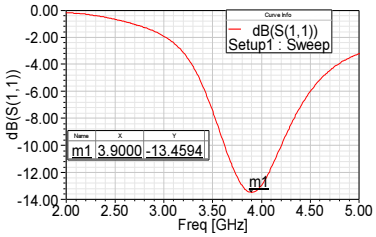
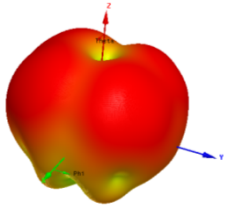


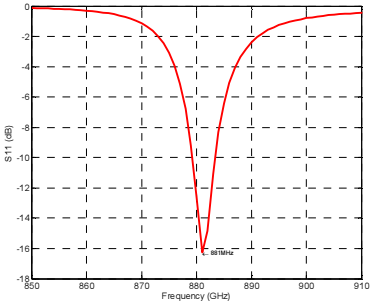
SRR cell

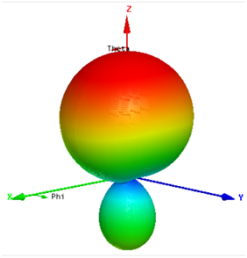
=>







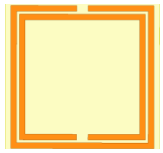
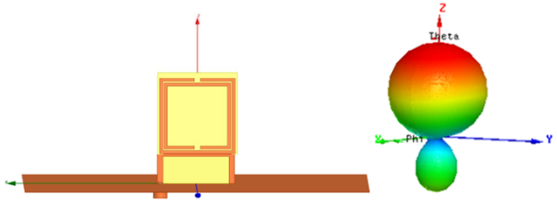
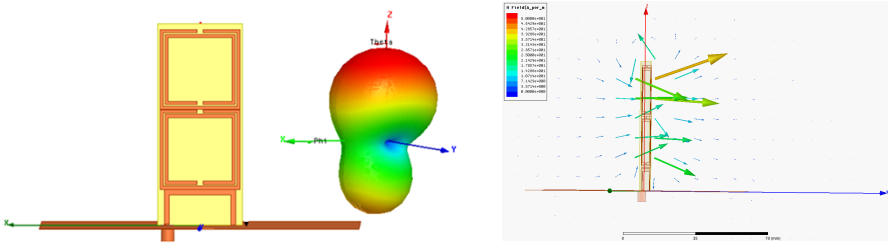
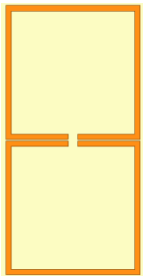
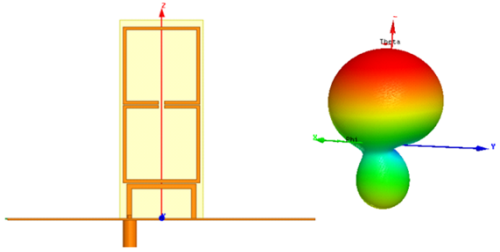
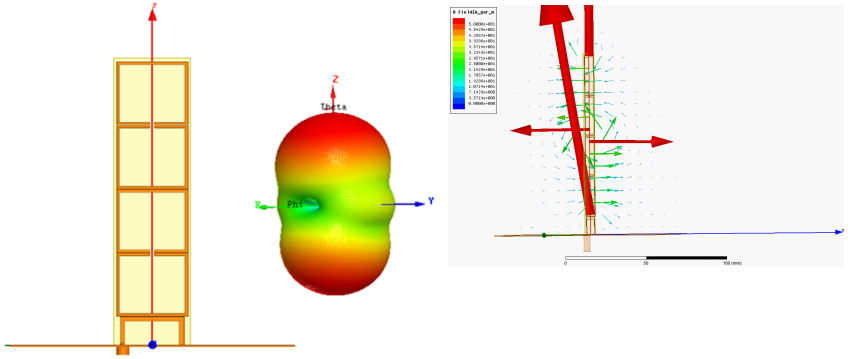




- F=3,9GHz
- Null radiation in z-axis

- F=881MHz (77% frequency shift)
- Radiation focused in z-axis

SRR and C resonators cells effects comparison

Half-loop +	One cell	Two cells
 SRR	 ▪ F = 881MHz (77% shift) ▪ Directivity = 4.2 dB ▪ η = 91%	 ▪ F = 739MHz (81% shift) ▪ Directivity = 3.1dB ▪ η = 91%
 C resonators	 ▪ F = 945MHz (75% shift) ▪ Directivity = 4.9dB ▪ η = 60%	 ▪ F = 920MHz (76% shift) ▪ Directivity = 7.35dB ▪ η = 31%

Summary

- Add SRR cells to a half-loop antenna:
  - Important resonance frequency shifting
  - Good efficiency
  - Less directive

- Add C resonators cells to a half-loop antenna:
  - Less resonance frequency shifting
  - Bad efficiency
  - More directive

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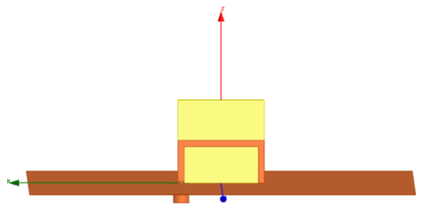
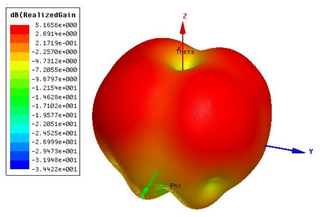
Abstract

The effect of associating Split Ring Resonators (SRR) or C resonators cells with a half-loop antenna is studied :

- Adding SRRs will shift down considerably the resonance frequency but the directivity will be almost the same. SRRs are good candidate for antenna miniaturization.
- Adding C resonators will increase more the directivity while the frequency shifting is not as important as with SRR cells. **With a ground plane of 10cm x 10cm, two cells of C resonators coupled with a half-loop antenna have a directivity of 7.35dB at 920.4MHz**.

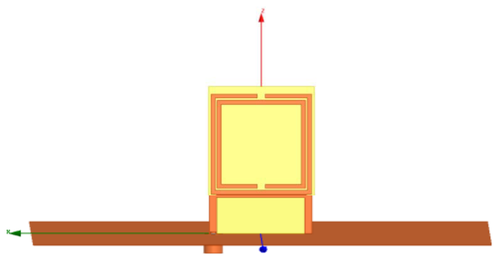
Add one SRR cell => Frequency shift and focus effect

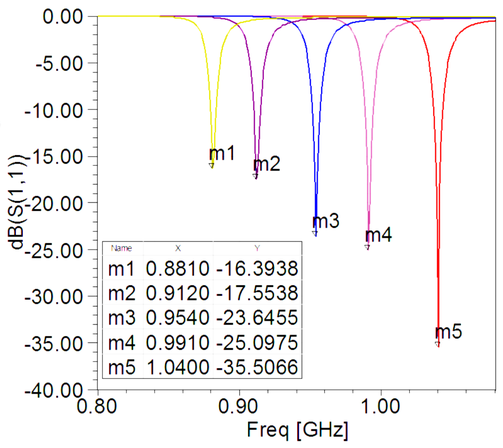




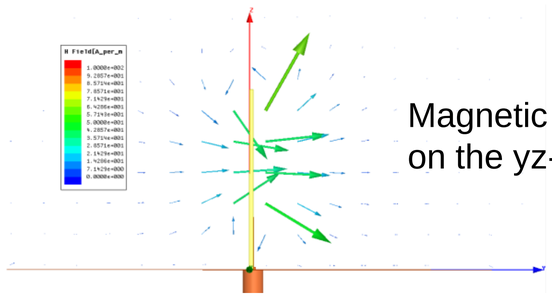
Add one SRR cell

- **The new resonance frequency depends on the SRR cell size**
- **Radiation pattern focused in z-axis**

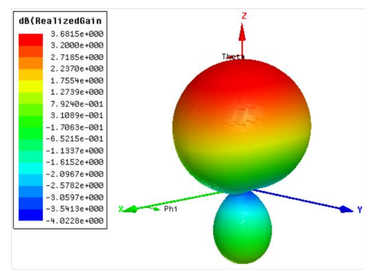




Frequency variation with the external dimension of the SRR cell



Magnetic field distribution on the yz-plane



Half-loop antenna

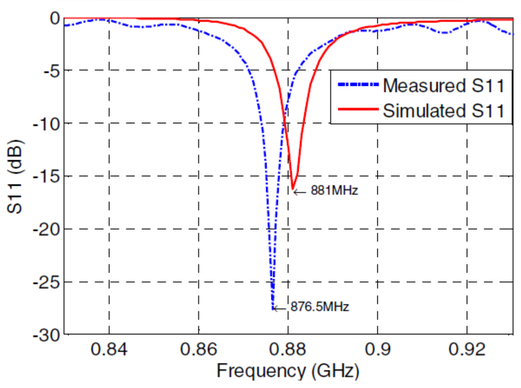
- **F= 3.9 GHz**
- **Gain = 5 dBi**

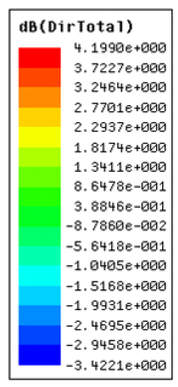
Half-loop antenna + SRR cell

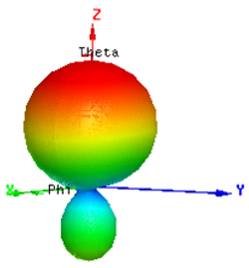
- **F= 0.881 GHz => 77% frequency shift**
- **Gain = 3.7 dBi**

SRRs and C resonators cells effects comparison

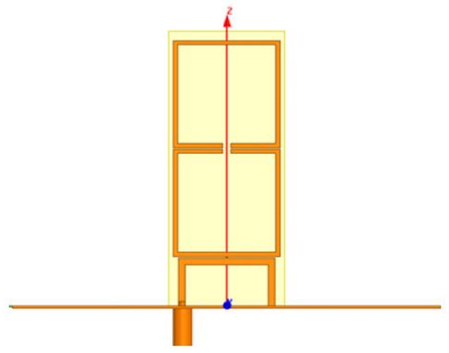
ONE CELL

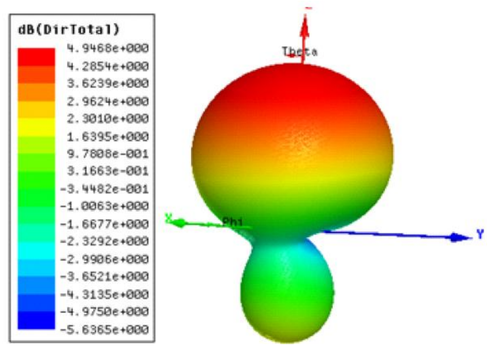






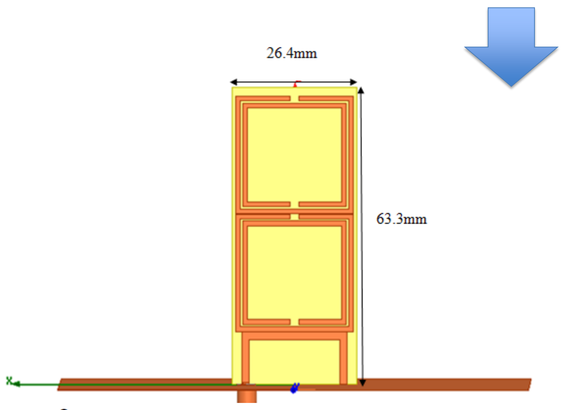
- **F = 881MHz (77% shift)**
- **Directivity = 4.2 dB**
- **η = 91%**

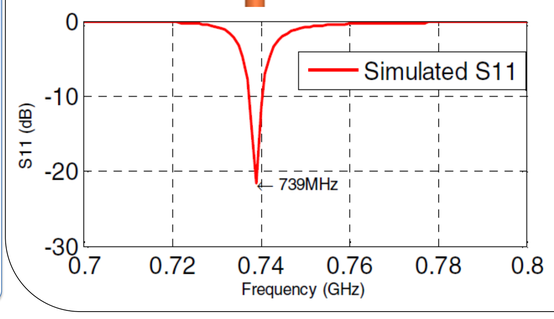


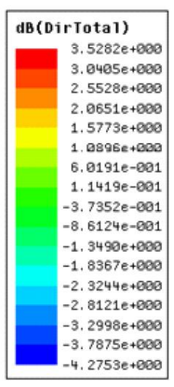


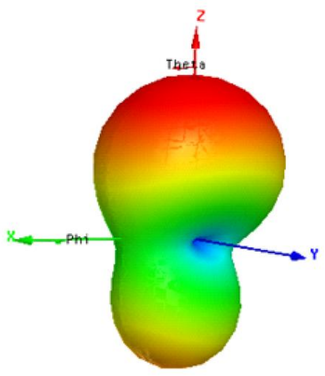
- **F = 945MHz (75% shift)**
- **Directivity = 4.9dB**
- **η = 60%**

TWO CELLS

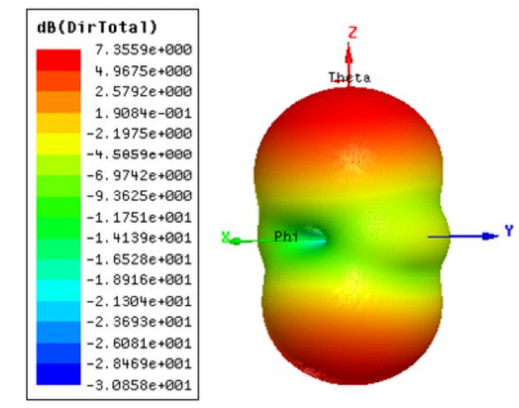


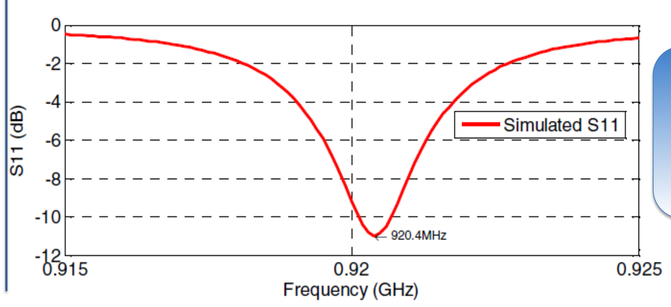






- **F = 739MHz (81% shift)**
- **Directivity = 3.5dB**
- **η = 91%**





- **F = 920MHz (76% shift)**
- **Directivity = 7.35dB**
- **η = 31%**

Conclusion and perspective

- **Add SRR cells to a half-loop antenna:**
  - Important resonance frequency shifting
  - Good efficiency
  - Less directive
- **Add C resonators cells to a half-loop antenna:**
  - Less resonance frequency shifting
  - Bad efficiency
  - More directive
- **Future work:** Minimize the loss of the half-loop antenna coupled with two C resonators cells to increase its efficiency.

Esthelladi Ramanandraibe was born in Antananarivo, Madagascar on February 1988. She received the Radio Frequency Engineering diploma from the *Ecole Supérieure Polytechnique d'Antananarivo*, Antananarivo, Madagascar, and the M.S. degree in industrial data processing from the *Université Pierre et Marie Curie*, Paris, France, in 2010 and 2011 respectively. She is currently pursuing a Ph.D in Radio Frequency and Microwave in *ESEO*, Angers, France and *Université de Rennes 1*, Rennes, France. Her topics of interest are RFID technology, antenna miniaturization and optimization using metamaterials.

Biography: Mohamed LATRACH

Mohamed Latrach (IEEE member) received the Ph.D. degree in electronics from the University of Limoges, Limoges, France, in 1990. He is currently Professor of microwave engineering with the *Ecole Supérieure d'Electronique de l'Ouest (ESEO*), Angers, France, where he is head of the Radio-Frequency & Microwave research group. His research interests include: design of hybrid & monolithic active and passive microwave circuits, metamaterials, LH materials, antennas, rectennas and their applications in wireless communications, and wireless power transmission (WPT).

Mohamed LATRACH has supervised several Ph.D students, postdoctoral students and master/engineer students, with many publications in national and international conferences and journals. He has been involved in several projects. For example, he is currently the leader for ESEO of the SPINNAKER project, which is an important collaborative project between academic and industrial partners, which deals with the design of new antennas structures for RFID Applications. He has also filed 2 patents, on antennas structures involving metamaterials, in France.

Ala Sharaiha received the Ph.D. and Habilitation à Diriger la Recherche (HDR) degrees in telecommunication from the University of Rennes 1, France, in 1990 and 2001 respectively. Currently, he is a Full Professor at the University of Rennes 1, Rennes, France and the Co-Head of the 'Complex Radiation Systems" Team in the 'Antennas and Microwave Devices' Department.
His main research activities include small antennas, broadband and UWB antennas, reconfigurable antennas, printed spiral and helical antennas, antennas for mobile communications, etc. Conducted and involved in more than 20 industrial and collaborative projects.

Prof. Sharaiha has published more than 250 journal and conference papers, concerning antenna theory, analysis, design and measurements, and he holds 12 patents. His published works have been cited over 500 times in Google Scholar. He has graduated/mentored over 20 Ph.D. students/post-docs, and co-authored with them.

He is presently a member of the European School of Antennas Board and a member of the small antennas working group of the European Association on Antennas and Propagation (EuRAAP). He is a senior member of the IEEE and is a reviewer for the IEEE APS, IEEE AWPL, the IET Letters and the IET Microwave Antennas Propagation. He was the conference Chairman of the 11th International Canadian Conference ANTEM (Antenna Technology and Applied Electro- Magnetics), held at Saint-Malo in France, 2005.